

BAYOU BOEUF, HALPIN CANAL, AND THERIOT CANAL AND
LAKE BOEUF
TMDLS FOR BIOCHEMICAL OXYGEN-DEMANDING SUBSTANCES

SUBSEGMENTS 020102 AND 020103

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REVISED TMDL REPORT

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EXECUTIVE SUMMARY

This report presents the results of calibrated dissolved oxygen (DO) modeling and total maximum daily load (TMDL) calculations for subsegments 020102 (Bayou Boeuf, Halpin Canal, and Theriot Canal) and 020103 (Lake Boeuf). The modeling was conducted to establish TMDLs for biochemical oxygen-demanding pollutants for these subsegments. Subsegments 020102 and 020103 are located in southern Louisiana in the Barataria basin west of New Orleans. These subsegments have a combined area of approximately 120 mi² (311km²). The two predominant land uses in subsegment 020102 are wetland forest and agriculture, while subsegment 020103 is classified as mostly fresh marsh and open water. Two point source discharges were included in the model, and several other small point source discharges within the subsegments were also included in the TMDL.

Inputs for the calibration model were developed from data collected during the June 2003 intensive survey, data collected by the Louisiana Department of Environmental Quality (LDEQ) at three monitoring stations in the watershed, the LDEQ Reference Stream Study, and NPDES permits and permit applications for each of the point source dischargers. A satisfactory calibration was achieved for the model. In those cases where the calibration was not as accurate, the difference was in the conservative direction. For the projection models, data were taken from current discharge permits, current applications, and ambient temperature records. The Louisiana TMDL Technical Procedures manual (dated 09/23/2003) has been followed in this study.

Modeling was limited to low flow scenarios for both the calibration and the projections since the constituent of concern was dissolved oxygen and the available data was limited to low flow conditions. The model used was LA-QUAL, a modified version of QUAL-TX, which has been adapted to address specific needs of Louisiana waters.

Subsegments 020102 and 020103 were listed as impaired on both the EPA 1999 Court Ordered 303(d) list for Louisiana and the LDEQ Final 2002 303(d) list. These subsegment were found to be not supporting their designated use of fish and wildlife propagation. Subsegments 020102 and 020103 were subsequently scheduled for TMDL development with other listed waters in the Barataria basin. According to the 1999 Court Ordered 303(d) list, the suspected causes of impairment included organic enrichment / low DO and nutrients; and the suspected sources were minor industrial point sources, pasture land, petroleum activities, spills, septic tanks, natural sources, and non-irrigated crop production. These TMDLs address the organic enrichment / low DO impairment and the nutrient impairment.

Based on the results of the projection modeling, meeting the water quality standard for DO of 5.0 mg/L will require man made sources to be reduced by 100% in summer and 92% in winter and natural background sources will have to be reduced by 37% in the summer. The no-load scenarios (i.e., no reduction in natural background sources) yielded minimum DO values of 3.5 mg/L for summer and 5.6 mg/L for winter. This suggests that the existing DO standard for these subsegments is definitely not appropriate for summer.

Nonpoint source load calculations and TMDL calculations were performed using LDEQ's standard TMDL spreadsheet. This spreadsheet calculates wasteload allocations (WLAs) for point sources, load allocations (LAs) for man-made nonpoint sources and natural nonpoint sources, and incorporates an explicit margin of safety (MOS). For these TMDLs, the explicit MOS was set to 20% of the sum of the man-made nonpoint sources and the point sources. This MOS accounts for future growth as well as lack of knowledge concerning the relationship between pollutant loads and water quality. The explicit MOS is provided in addition to the implicit MOS, which is created by conservative assumptions in the modeling. A summary of the TMDLs is provided in Tables ES.1 and ES.2.

Table ES.1. TMDL for subsegment 020102 (sum of CBOD_u, NBOD_u, and SOD).

	Summer (May-Oct)		Winter (Nov-Apr)	
	Reduction	Load (kg/day)	Reduction	Load (kg/day)
Point Source WLA	0%	123	0%	123
Point Source Reserve MOS (20%)		31		31
Natural Nonpoint Source LA	37%	2732	0%	3772
Natural Nonpoint Source MOS (0%)		0		0
Man-made Nonpoint Source LA	100%	0	92%	420
Man-made Nonpoint Source MOS (20%)		0		105
TMDL	--	2886	--	4451

Table ES.2. TMDL for subsegment 020103 (sum of CBOD_u, NBOD_u, and SOD).

	Summer (May-Oct)		Winter (Nov-Apr)	
	Reduction	Load (kg/day)	Reduction	Load (kg/day)
Point Source WLA	0%	0	0%	0
Point Source Reserve MOS (20%)		0		0
Natural Nonpoint Source LA	37%	9003	0%	13360
Natural Nonpoint Source MOS (0%)		0		0
Man-made Nonpoint Source LA	100%	0	92%	7
Man-made Nonpoint Source MOS (20%)		0		2
TMDL	--	9003	--	13369

These subsegments were listed as impaired due to nutrients as well as organic enrichment / low DO. These TMDLs establish load limitations for oxygen-demanding substances and goals for reduction of those pollutants. LDEQ's position, as stated in the declaratory ruling issued by Dale Givens regarding water quality criteria for nutrients (Sierra Club v. Givens, 710 So.2d 249 (La. App. 1st Cir. 1997), writ denied, 705 So.2d 1106 (La. 1998), is that when oxygen-demanding substances are controlled and limited in order to ensure that the dissolved oxygen criterion is supported, nutrients are also controlled and limited. The implementation of these TMDLs through wastewater discharge permits and implementation of best management practices to

control and reduce runoff of soil and oxygen-demanding pollutants from nonpoint sources in the watershed will also control and reduce the nutrient loading from those sources.

LDEQ will work with other agencies such as local Soil Conservation Districts to implement agricultural best management practices in the watershed through the 319 programs. LDEQ will also continue to monitor the waters to determine whether standards are being attained.

In accordance with Section 106 of the federal Clean Water Act and under the authority of the Louisiana Environmental Quality Act, the LDEQ has established a comprehensive program for monitoring the quality of the state's surface waters. The LDEQ Surveillance Section collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state's surface waters, to develop a long-term data base for water quality trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state's biennial 305(b) report (*Water Quality Inventory*) and the 303(d) list of impaired waters. This information is also utilized in establishing priorities for the LDEQ nonpoint source program.

The LDEQ has implemented a watershed approach to surface water quality monitoring. Through this approach, the entire state is sampled over a four-year cycle. Long-term trend monitoring sites at various locations on the larger rivers and Lake Pontchartrain are sampled throughout the four-year cycle. Sampling is conducted on a monthly basis to yield approximately 12 samples per site each year the site is monitored. Sampling sites are located where they are considered to be representative of the waterbody. Under the current monitoring schedule, approximately one-half of the states waters are newly assessed for 305(b) and 303(d) listing purposes for each biennial cycle with sampling occurring statewide each year. The four year cycle follows an initial five year rotation which covered all basins in the state according to the TMDL priorities. This will allow the LDEQ to determine whether there has been any improvement in water quality following implementation of the TMDLs. As the monitoring results are evaluated at the end of each year, waterbodies may be added to or removed from the 303(d) list.

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The intensive survey was performed by LDEQ watershed survey personnel and the laboratory analyses of water samples were performed by LDEQ laboratory personnel. Initial compilation of some of the field data was done by LDEQ watershed survey personnel.

The field data analysis, water quality modeling, TMDL calculations, and preparation of the report were performed by several FTN personnel including Richard Bennett, Christine Richmond, Christina Laurin, and Philip Massirer.

ABBREVIATIONS

BMP	best management practice
BOD	biochemical oxygen demand
CBOD _u	ultimate carbonaceous biochemical oxygen demand
CFR	Code of Federal Register
cfs	cubic feet per second
CWPPRA	Coastal Wetlands Planning, Protection, and Restoration Act
DO	dissolved oxygen
EPA	Environmental Protection Agency
FTN	FTN Associates, Ltd.
ft/sec	feet per second
g/m ² /day	grams per square meter per day
kg/day	kilograms per day
km	kilometer
LA	load allocation
LAC	Louisiana Administrative Code
lbs/day	pounds per day
LC	loading capacity
LDEQ	Louisiana Department of Environmental Quality
LDNR	Louisiana Department of Natural Resources
LTP	Louisiana TMDL Technical Procedures Manual
MGD	million gallons per day
NBOD _u	ultimate nitrogenous biochemical oxygen demand
NCM	nonconservative material
NPDES	National Pollutant Discharge Elimination System
mg/L	milligrams per liter
TMDL	total maximum daily load
USGS	United States Geological Survey
WLA	wasteload allocation

1. Introduction

This report presents total maximum daily loads (TMDLs) for biochemical oxygen demanding substances for subsegments 020102 (Bayou Boeuf, Halpin Canal, and Theriot Canal) and 020103 (Lake Boeuf). These subsegments were listed as impaired on both the 1999 Court Ordered 303(d) List for Louisiana (EPA 1999) and the Louisiana Department of Environmental Quality (LDEQ) Final 2002 303(d) List (LDEQ 2003a). On both of these 303(d) lists, organic enrichment/low dissolved oxygen (DO) and nutrients were cited as suspected causes of impairment. Therefore, development of TMDLs for biochemical oxygen demanding substances was required. A calibrated water quality model was developed and projections were simulated to quantify the load reductions which would be necessary in order for these subsegments to comply with established water quality standards and criteria. The TMDLs in this report were developed in accordance with the LDEQ TMDL Technical Procedures Manual (known as the "LTP") (LDEQ 2003b) as well as federal requirements in Section 303(d) of the Federal Clean Water Act and the Environmental Protection Agency's (EPA) regulations in 40 CFR 130.7.

2. Study Area Description

2.1 General Information

Subsegments 020102 and 020103 are located in southern Louisiana in the Barataria basin west of New Orleans (see Figure A1.1 in Appendix A1). Subsegment 020102 includes four main bayous and canals (Bayou Boeuf, Halpin Canal, Theriot Canal, and Grand Bayou) and numerous other smaller bayous and canals, many of which are interconnected. Subsegment 020103 includes only Lake Boeuf and is completely surrounded by subsegment 020102.

These two subsegments are bounded on the north by a slight natural ridge between Grand Bayou and Bayou Chevreuil and on the south by the natural ridge along Bayou Lafourche. The overall drainage pattern for these subsegments is towards Lac des Allemands. Two places where inflow from outside these subsegments can occur are the western end of Grand Bayou (a distributary of Bayou Citamon) and the southern end of Theriot Canal (which connects to Bayou Lafourche). The exchange of flow between Bayou Lafourche and Theriot Canal is limited by a gated structure near the south end of Theriot Canal. This structure is normally closed during low flow periods except to allow boats to pass through its opening, which is approximately 8 ft wide. The structure is owned by the Bayou Lafourche Freshwater Diversion District.

These subsegments have a combined area of approximately 120 mi² (311 km²). The two predominant land uses in subsegment 020102 are wetland forest and agriculture, while subsegment 020103 is classified as mostly fresh marsh and open water. Land use data for these subsegments are summarized in Table 2.1 and shown spatially on Figure A1.2 (in Appendix A1). Because much of Lake Boeuf is covered by relatively thick densities of floating and/or rooted vegetation, a large portion of subsegment 020103 (over 67%) was classified as marsh instead of water. The majority of the agricultural land (and other developed land) in subsegment 020102 is located near the ridge along Bayou Lafourche. The primary crop in this area is sugarcane.

Table 2.1. Land use for subsegments 020102 and 020103.

Land Use Type	Percent of Total Area (020102)	Percent of Total Area (020103)
Fresh Marsh	9.0%	67.6%
Saline Marsh	0.0%	0.0%
Wetland Forest	62.1%	0.0%
Upland Forest	0.1%	0.0%
Wetland Scrub/Shrub	2.3%	5.6%
Upland Scrub/Shrub	0.0%	0.0%
Agriculture	20.2%	0.0%
Urban	3.0%	0.0%
Barren	0.0%	0.0%
Water	3.3%	26.8%
TOTAL	100.0%	100.0%

2.2 Water Quality Standards

The designated uses and numeric water quality standards for subsegments 020102 and 020103 are listed below in Table 2.2. These subsegments have a year round DO standard of 5.0 mg/L.

Table 2.2. Water quality numeral criteria and designated uses (LDEQ 2003c).

Subsegment Number	020102	020103
Subsegment Name	Bayou Boeuf, Halpin Canal, and Theriot Canal	Lake Boeuf
Designated Uses	A, B, C, F	A, B, C
Criteria:		
DO	5 mg/L	5 mg/L
Chloride	500 mg/L	500 mg/L
Sulfate	150 mg/L	150 mg/L
pH	6.0 – 8.5	6.0 – 8.5
Bacteria	see note 1 below	see note 1 below
Temperature	32 °C	32 °C
TDS	1000 mg/L	1000 mg/L

USES: A – primary contact recreation; B – secondary contact recreation; C – propagation of fish and wildlife; D – drinking water supply; E – oyster propagation; F – agriculture; G – outstanding natural resource water; L – limited aquatic and wildlife use.

Note 1 – 200 colonies / 100 mL maximum log mean and no more than 25% of samples exceeding 400 colonies / 100 mL for May through October; 1000 colonies / 100 mL maximum log mean and no more than 25% of samples exceeding 2000 colonies / 100 mL for November through April.

As specified in EPA's regulations at 40 CFR 130.7(b)(2), applicable water quality standards include antidegradation requirements. The LDEQ antidegradation policy (LAC 33: IX.1109.A)

includes the following statements that are applicable to this TMDL: "No lowering of water quality will be allowed in waters where standards for the designated water uses are not currently being attained. ... The administrative authority will not approve any wastewater discharge or certify any activity for federal permit that would impair water quality or use of state waters." The TMDLs in this report are consistent with the LDEQ antidegradation policy.

2.3 Point Sources

A total of 9 National Pollutant Discharge Elimination System (NPDES) permits were identified for point source discharges within subsegment 020102; none were identified for subsegment 020103. Information for these point source discharges is shown in Appendix A2. This information was obtained by reviewing data from both the LDEQ point source database and from a point source database prepared for the Barataria and Terrebonne basins under contract to EPA Region 6. The locations of these facilities are shown on Figure A2.1 (in Appendix A2). Only two of these facilities discharge directly into the waterbodies of interest in these subsegments (Theriot Canal, Lake Boeuf, Bayou Boeuf, Halpin Canal, and Grand Bayou). Both of these two facilities (Kraemer Bridge and Boeuf Elementary School) have small discharges.

2.4 Nonpoint Sources

Suspected nonpoint sources for subsegments 020102 and 020103 have been listed in the 1999 Court Ordered 303(d) List for Louisiana (EPA 1999). Suspected nonpoint sources for 020102 include non-irrigated crop production, pastureland, petroleum activities, septic tanks, spills, and natural sources. Suspected nonpoint sources for 020103 include non-irrigated crop production and pastureland. Based on LDEQ's experience in the Barataria basin, it is suspected that there is considerable nonpoint source oxygen demand in these subsegments that is natural (i.e., not induced by human activities).

2.5 Water Quality Conditions/Assessment

As mentioned in Section 1, this subsegment was listed as impaired by both EPA and LDEQ due to organic enrichment / low DO and nutrients. Information from the EPA 303(d) listings are shown in Table 2.3 below. The water quality data that LDEQ used to assess these subsegments and include them on the 303(d) list were ambient monitoring data collected by LDEQ at several monitoring stations. The locations of the ambient monitoring stations are shown on Figure A1.1, and the DO data are listed in Appendix B. As shown in Table 2.4, DO measurements less than 5 mg/L are common at all three stations.

Table 2.3. 303(d) listing for subsegments 020102 and 020103 (EPA 1999).

Subsegment	Description	Suspected sources	Suspected causes	Priority ranking (1=highest)
020102	Bayou Boeuf, Halpin Canal and Theriot Canal	Minor industrial point sources Non-irrigated crop production Pastureland Petroleum activities Septic tanks Spills Natural	Pesticides Nutrients Organic enrichment/low DO Oil & Grease Priority organics Salinity/TDS/chlorides/sulfates Radiation Noxious aquatic plants	3
020103	Lake Boeuf	Non-irrigated crop production Pasture land	Pesticides Nutrients Organic enrichment/low DO Noxious aquatic plants	3

Table 2.4. Summary of historical DO data for subsegments 020102 and 020103.

LDEQ Subsegment	LDEQ Station	Station Description	Period of Record			No. of DO values <5.0 mg/L	Percent of DO values <5.0 mg/L
			Begin	End	No. of values		
020102	0083	Grand Bayou near Chegby (chackbay), Louisiana	6/1/58	5/12/98	398	367	92%
020102	0918	Bayou Boeuf at Halpin Canal, Louisiana	1/19/00	12/13/00	12	9	75%
020103	0919	Lake Boeuf north of Theriot Canal, Louisiana	1/19/00	12/13/00	12	10	83%

2.6 Previous Studies and Data

No previous water quality studies have been identified for subsegments 020102 and 020103. There are no US Geological Survey (USGS) or Corps of Engineers stage gages or flow gages in the subsegments. The only historical water quality data that are known to exist are the LDEQ data mentioned in Section 2.5.

3. Field Survey

An intensive field survey was conducted by LDEQ personnel in subsegments 020102 and 020103 during the week of June 16-20, 2003. The purpose of this survey was to gather information about the subsegment and collect data that would be needed to set up and calibrate a water quality model. The field data that were collected included water quality samples and in situ measurements, continuous in situ monitoring, cross sections, acoustic Doppler flow measurements, drogue measurements, and two dye studies for time of travel. Continuous in situ monitoring data (temperature, DO, pH, and specific conductivity) were collected from June 17 to June 19. Water quality samples and associated in situ data were taken on June 18. Maps and descriptions of the field data collection sites are included in Appendix C1.

3.1 Water Quality Sampling and In Situ Data

The water quality sampling data and the in situ data collected with the water quality samples are shown in Table C2.1 (in Appendix C2). The only station that had a DO reading above the water quality standard of 5.0 mg/L was TC-1 on Theriot Canal. Table C2.2 shows a comparison of data collected at GB-2 and BBf-1 during the survey with LDEQ historical data collected at stations 0083 and 0918 (same locations as GB-2 and BBf-1). This comparison shows that in general, the survey data appear to be representative of summer conditions in this system.

3.2 Continuous Monitoring Data

Figures C3.1 through C3.72 (in Appendix C3) show plots of the continuous in situ data collected during the survey. The diurnal fluctuations of DO ranged from about 1.0 mg/L to about 4.3 mg/L at all stations except TC-1, where the diurnal fluctuation of DO was about 6.6 mg/L. DO percent saturation levels exceeded 100% at only one station (TC-1). Diurnal fluctuations of pH were small (<0.3 su) at all stations except at TC-1, where the diurnal fluctuation exceeded 1.0 su. The absence of large DO fluctuations and supersaturated DO values suggest that algal productivity is generally low at stations within these subsegments. The continuous conductivity data showed some temporal and spatial variability, but there were no obvious explanations for the variations. Continuous water level data were also measured, but they did not show any significant diurnal fluctuations.

3.3 BOD Time Series Analyses

Results of 60-day BOD time series analyses are shown in Appendix C4. For each sample, values of cumulative oxygen demand and $\text{NO}_2 + \text{NO}_3$ concentration were obtained at selected intervals over a period of about 60 days. These data were entered into an LDEQ spreadsheet called GSBOD, which contains algorithms for fitting first order curves to the data to calculate values of ultimate carbonaceous biochemical oxygen demand (CBODu), ultimate nitrogenous biochemical oxygen demand (NBODu), decay rates for both CBODu and NBODu, and lag times for both CBODu and NBODu. The results of these analyses are shown in Appendix C4. The NBODu decay rates for the Grand Bayou stations were generally higher than for other stations. The CBODu decay rates showed relatively little spatial variability.

3.4 Cross Section Data

Cross sections were measured at 6 water quality sampling locations and 16 other locations for the dye studies. These cross section data are shown in Appendix C5.

3.5 Velocity and Flow Measurements

Table C6.1 (in Appendix C6) shows acoustic Doppler and manual flow measurements made at the sampling sites. All of the measured flows were positive (i.e., flow towards Lac des Allemands). For stations where measurements were taken on both June 17 and June 18, the flows were not consistently lower on one day and higher on the other day.

Table C6.2 (in Appendix C6) shows velocity measurements made with drogues and flows that were estimated from those velocities. Except for several measurements that appeared to be influenced by the wind, most of the measurements and field notes indicated downstream flow (i.e., towards Lac des Allemands) on June 17 and June 18. In some cases, there were wide variations between drogue velocities at the same station on June 17 and on June 18 (partly due to differences in the wind speed and direction on each day). There was no consistent pattern of flows being higher on one day and lower on the other day.

Two dye studies were conducted to measure velocity in this system. One slug of dye was injected in Bayou Boeuf near BBf-1 and another was injected in Grand Bayou near GB-3. Appendix C6 contains time of travel calculations (Tables C6.3 and C6.4) as well as plots of dye concentration versus time at these two locations (Figures C6.1 and C6.2). In both dye studies, the dye was injected during the morning of June 18 and the first two “runs” were made that day and a third “run” was made on June 19. For both dye studies, the dye moved downstream of the injection location (i.e., towards Lac des Allemands) throughout the duration of the dye studies. No reversing flow was indicated by the dye studies.

3.6 Dispersion Coefficients

The results of the dye studies mentioned in Section 3.5 were also used to calculate dispersion coefficients by fitting theoretical curves of dye concentration vs. distance to the observed data (the dispersion coefficient was adjusted so that the shape of the theoretical curve was similar to the observed data). Table C7.1 shows a summary of the dispersion coefficients and Tables C7.2 through C7.7 show calculations for each dye run. Figures C7.1 through C7.6 show comparisons of the theoretical dye curves and the observed data.

4. Documentation of Calibration Model

4.1 Program Description

"Simulation models are used extensively in water quality planning and pollution control. Models are applied to answer a variety of questions, support watershed planning and analysis and develop total maximum daily loads (TMDLs). ... Receiving water models simulate the movement and transformation of pollutants through lakes, streams, rivers, estuaries, or near shore ocean areas. ... Receiving water models are used to examine the interactions between loadings and response, evaluate loading capacities (LCs), and test various loading scenarios. ... A fundamental concept for the analysis of receiving waterbody response to point and nonpoint source inputs is the principle of mass balance (or continuity). Receiving water models typically develop a mass balance for one or more constituents, taking into account three factors: transport through the system, reactions within the system, and inputs into the system." (EPA841-B-97-006, pp. 1-30)

The model used for this TMDL was LA-QUAL, a steady-state one-dimensional water quality model. LA-QUAL has the mechanisms for incorporating hydraulic characteristics of Louisiana waterbodies and was particularly suitable for use in modeling Main Canal. LA-QUAL history dates back to the QUAL-I model developed by the Texas Water Development Board with Frank D. Masch & Associates in 1970 and 1971. William A. White wrote the original code.

In June, 1972, EPA awarded Water Resources Engineers, Inc. (now Camp Dresser & McKee) a contract to modify QUAL-I for application to the Chattahoochee-Flint River, the Upper Mississippi River, the Iowa-Cedar River, and the Santee River. The modified version of QUAL-I was known as QUAL-II.

Over the next three years, several versions of the model evolved in response to specific client needs. In March, 1976, the Southeast Michigan Council of Governments (SEMCOG) contracted with Water Resources Engineers, Inc. to make further modifications and to combine the best features of the existing versions of QUAL-II into a single model. That became known as the QUAL-II/SEMCOG version.

Between 1978 and 1984, Bruce L. Wiland with the Texas Department of Water Resources modified QUAL-II for application to the Houston Ship Channel estuarine system. Numerous modifications were made to enable modeling this very large and complex system including the addition of tidal dispersion, lower boundary conditions, nitrification inhibition, sensitivity analysis capability, branching tributaries, and various input/output changes. This model became known as QUAL-TX and was subsequently applied to streams throughout the State of Texas.

In 1999, LDEQ and Wiland Consulting, Inc. developed LA-QUAL based on QUAL-TX Version 3.4. The program was converted from a DOS-based program to a Windows-based program with a graphical interface and enhanced graphic output. Other program modifications specific to the needs of Louisiana and the LDEQ were also made. LA-QUAL is a user-oriented model and is intended to provide the basis for evaluating total maximum daily loads in the State of Louisiana.

The development of a TMDL for dissolved oxygen generally occurs in 3 stages. Stage 1 encompasses the data collection activities. These activities may include gathering such information as stream cross-sections, stream flow, stream water chemistry, stream temperature and dissolved oxygen and various locations on the stream, location of the stream centerline and the boundaries of the watershed which drains into the stream, and other physical and chemical factors which are associated with the stream. Additional data gathering activities include gathering all available information on each facility which discharges pollutants in to the stream, gathering all available stream water quality chemistry and flow data from other agencies and groups, gathering population statistics for the watershed to assist in developing projections of future loadings to the water body, land use and crop rotation data where available, and any other information which may have some bearing on the quality of the waters within the watershed. During Stage 1, any data available from reference or least impacted streams which can be used to gauge the relative health of the watershed is also collected.

Stage 2 involves organizing all of this data into one or more useable forms from which the input data required by the model can be obtained or derived. Water quality samples, field measurements, and historical data must be analyzed and statistically evaluated in order to determine a set of conditions which have actually been measured in the watershed. The findings are then input to the model. Best professional judgment is used to determine initial estimates for parameters which were not or could not be measured in the field. These estimated variables are adjusted in sequential runs of the model until the model reproduces the field conditions which were measured. In other words, the model produces a value of the dissolved oxygen, temperature, or other parameter which matches the measured value within an acceptable margin of error at the locations along the stream where the measurements were actually made. When this happens, the model is said to be calibrated to the actual stream conditions. At this point, the model should confirm that there is an impairment and give some indications of the causes of the impairment. If a second set of measurements is available for slightly different conditions, the calibrated model is run with these conditions to see if the calibration holds for both sets of data. When this happens, the model is said to be verified.

Stage 3 covers the projection modeling which results in the TMDL. The critical conditions of flow and temperature are determined for the waterbody and the maximum pollutant discharge conditions from the point sources are determined. These conditions are then substituted into the model along with any related condition changes which are required to perform worst case scenario predictions. At this point, the loadings from the point and nonpoint sources (increased by an acceptable margin of safety) are run at various levels and distributions until the model output shows that dissolved oxygen criteria are achieved. It is critical that a balanced distribution of the point and nonpoint source loads be made in order to predict any success in future achievement of water quality standards. At the end of Stage 3, a TMDL is produced which shows the point source permit limits and the amount of reduction in man-made nonpoint source pollution which must be achieved to attain water quality standards. The man-made portion of the nonpoint source pollution is estimated from the difference between the calibration loads and the loads observed on reference or least impacted streams.

4.2 Input Data Documentation

Data collected during the June 2003 intensive survey (described in Section 3) were used to establish the input for the model calibration. This survey was conducted during a period of low flows and warm temperatures.

The flows in the model were determined based on dye study results, selected drogoue measurements, and acoustic Doppler flows. Flow calculations are discussed in Section 4.2.11. A simulation of conservative constituents (e.g., chloride and conductivity) was performed to check the flow balance as discussed in Section 4.3.1.

Field and laboratory water quality data were entered in a spreadsheet for ease of analysis. The Louisiana GSBOD program was applied to the BOD time series data in a separate spreadsheet as described in Section 3. The survey data were the primary source for the model input data for initial conditions, decay rates, and inflow water quality.

4.2.1 Model Schematics and Maps

A vector diagram of the modeled area is presented in Figure 4.1 and also in Appendix D. The vector diagram shows the locations of survey stations, the reach design, the location of the modeled tributaries, and the locations of inflows. The reach design is discussed in Section 4.2.5. Maps showing the entire subsegment are included in Appendix A1.

4.2.2 Model Options, Data Type 2

Five constituents were modeled during the calibration process. These were chlorides, conductivity, dissolved oxygen (DO), CBOD_u, and NBOD_u. The chlorides and conductivity were included in the model for the purpose of checking the flow balance. NBOD_u was represented in the model as nonconservative material (NCM).

4.2.3 Program Constants, Data Type 3

Two program constants were specified in the model input. First, the hydraulic calculation method was specified as 2 rather than 1. Method 2 is the preferred method and allows the user to input widths and depths rather than velocities and depths. The other program constant that was specified was the NCM oxygen uptake rate, which was set to 1.0 mg of oxygen consumed per mg of NCM decayed.

4.2.4 Temperature Correction of Kinetics, Data Type 4

The temperature values in the model are used to correct the rate coefficients in the source/sink terms for the other water quality variables. These coefficients are input at 20°C and are then corrected to the stream temperatures using the following equation:



Figure 4.1. LA-QUAL vector diagram for subsegment 020102 and 020103.

$$X_T = X_{20} * \text{Theta}^{(T-20)}$$

where:

X_T = the value of the coefficient at the local temperature T in degrees Celsius

X_{20} = the value of the coefficient at the standard temperature (20 degrees Celsius)

Theta = an empirical constant for each reaction coefficient

In the absence of specified values for data type 4, the model uses default values. The default theta values include 1.047 for CBOD decay, 1.070 for nonconservative material (NBOD) decay, and 1.065 for SOD. All three of these default values were consistent with the LTP (LDEQ 2003b), so no values were explicitly specified in data type 4.

4.2.5 Reach Identification Data, Data Type 8

The model for this system simulated all of the waterbodies explicitly identified in the 303(d) lists (i.e., the waterbodies included in the subsegment names), which were Bayou Boeuf, Halpin Canal, Theriot Canal, and Lake Boeuf. Additionally, the model simulated Grand Bayou because it is a significant waterbody within subsegment 020102. Inflows and loadings from the remainder of subsegments 020102 and 020103 were included through tributary and nonpoint source contributions. A vector diagram of the model is shown in Appendix D.

As shown in the vector diagram, this system was modeled as three “branches” (Grand Bayou, Halpin Canal, and Theriot Canal/Lake Boeuf/Bayou Boeuf). Although the southeastern end of Halpin Canal does extend all the way to Theriot Canal, the model was separated at that confluence because field observations indicated that sedimentation and vegetation in the southeastern end of Halpin Canal were effectively preventing any significant exchange of water between Theriot Canal and Halpin Canal. This allowed the southeastern end of Halpin Canal to be represented as a headwater that was independent of the water quality in Theriot Canal.

Each “branch” was divided into reaches based primarily on changes in depth and width, but also based on changes in incremental inflow rates. The model was divided into a total of 19 reaches (2 reaches in Theriot Canal, 1 reach in Lake Boeuf, 3 reaches in Halpin Canal, 9 reaches in Grand Bayou, and 4 reaches in Bayou Boeuf). The element size was 0.10 km throughout the model.

4.2.6 Hydraulic Coefficients, Data Types 9 and 10

The hydraulics were specified in the model input for the LA-QUAL model using the power functions (width = $a * Q^b + c$ and depth = $d * Q^e + f$). Values specified in the model for these power functions are shown in Table E.1 in Appendix E. Based on the low gradient of streams in these subsegments and hydraulic conditions during the intensive field survey, it was assumed that changes in the stream flow rate between the calibration and projection simulations would create only negligible changes in depths and widths. Therefore, the coefficients and exponents (a, b, d, and e) were set to zero and the constants (c and f) were set based on the widths and depths

from measured cross sections. Plots of modeled and observed depths and widths are shown in Appendix F.

Dispersion was specified in the model using the dispersion coefficients calculated in Section 3.6. For each dye study, the coefficient from the last run was used since it reflected dispersion over the longest time interval. Because the dispersion coefficients for the last runs were similar between both dye studies ($2.12 \text{ m}^2/\text{sec}$ for Bayou Boeuf and $2.36 \text{ m}^2/\text{sec}$ for Grand Bayou), the average of these two values was used as the dispersion coefficient for all reaches. The dispersion coefficients used in the model are shown in Table E.1 in Appendix E.

4.2.7 Initial Conditions, Data Type 11

The initial conditions were used to specify the temperature and salinity for each reach and reduce the number of iterations required by the model for constituents being simulated. The values required for this model were temperature, salinity, and DO by reach. The input values came from the survey station(s) located closest to the reach or from an average of samples taken from stations located within the reach. For DO, the initial values were set to the calibration targets. The model inputs and data sources for the initial conditions are shown in Table E.2 in Appendix E.

Although chlorophyll data were available from the intensive survey, chlorophyll values were not specified in the initial conditions because the effects of algae on DO were taken into account through the determination of calibration target values for DO (discussed in Section 4.3.2).

4.2.8 Reaeration Rates, Data Type 12

For reaeration, the Louisiana equation was used for Theriot Canal (reaches 1-2) and the southeastern end of Halpin Canal (reach 5) because their depths (0.56 to 0.76 m) were within the range of values for which the Louisiana equation was developed (0.3 ft to 3.0; LDEQ 2003b). For all other reaches, the O'Connor-Dobbins equation (option 3) was used because the depths were greater than 3.0 ft but within the range of depths for which the O'Connor-Dobbins equation was developed (1 ft to 30 ft; LDEQ 2003b).

4.2.9 SOD, Data Type 12

The SOD values were achieved through calibration and ranged from $0.2 \text{ g/m}^2/\text{day}$ to $4.25 \text{ g/m}^2/\text{day}$. The SOD values used in the model are shown in Table E.4 in Appendix E. Results of the water quality calibration are discussed in Section 4.3.2.

4.2.10 CBODu and NBODu Rates, Data Types 12 and 15

The CBODu and NBODu decay rates used in the model were based on values calculated by the GSBOD spreadsheet for each station. Because the measured NBODu decay rates along Grand Bayou were slightly higher than for other parts of the system, the CBODu and NBODu decay rates for Grand Bayou were set to the averages of the values for the stations in Grand Bayou. The CBODu and NBODu decay rates for the rest of the system were set to the averages of the values

for all of the other stations (excluding tributary and downstream boundary stations). The individual decay rates are summarized in Table C4.1 (Appendix C4) and the values used in the model are shown in Table E.3 (Appendix E).

CBODu and NBODu settling rates were not used in the model because there was no information suggesting that simulating CBODu or NBODu settling was necessary. There were no point source discharges or other inflows that are known to be high in particulate CBODu or NBODu. The effects of settled CBODu and NBODu on DO are already implicitly included in the SOD.

4.2.11 Flow Calculations

The flows that were either measured directly or estimated from drogue velocities on June 17 and June 18 (discussed in Section 3.5) were used to compute a flow balance for each “branch” in the system. The procedures and assumptions used for computing these flow balances are outlined below. Calculations for incremental inflow are shown in Appendix G.

Halpin Canal:

1. The headwater flow was set to zero because there was assumed to be negligible inflow to Halpin Canal from Theriot Canal.
2. The incremental inflow per km between the headwater and HC-1 was calculated as the estimated flow at HC-1 (average of values for June 17 and June 18) divided by the distance between the headwater and HC-1.
3. The incremental inflow per km between HC-1 and HC-2 was assumed to be the same as between the headwater and HC-1.
4. Because the measured flow at HC-2 (average of values for June 17 and June 18) was much greater than the cumulative flow provided by incremental inflow, flow was added from two tributaries located between HC-1 and HC-2 (Pitre Lening Canal and Unnamed Canal). The total flow from those two tributaries combined was calculated as the measured flow at HC-2 (average of values for June 17 and June 18) minus the cumulative incremental inflow between the headwater and HC-2. The combined flow for Pitre Lening Canal and Unnamed Canal was divided equally between them.
5. The incremental inflow between HC-2 and Bayou Boeuf was assumed to be zero based on the flow balance for Bayou Boeuf.

Grand Bayou:

1. The headwater flow was set to the measured and estimated flows at GB-1 (average of values for June 17 and June 18).
2. The tributary flow for Bayou Onion was set to the estimated flow at BO-1 (average of values for June 17 and June 18).
3. Flow from LaPeans Canal was not included in the model because drogue measurements at LPC-1 indicated no flow on both June 17 and June 18.
4. The incremental inflow per km between the headwater and GB-6 was calculated by taking the measured flow at GB-6 (average of values for June 17 and June 18) and subtracting the inflows from the headwater and Bayou Onion, and then dividing by the distance between the headwater and GB-6.

5. The incremental inflow between GB-6 and Bayou Boeuf was assumed to be zero based on the flow balance for Bayou Boeuf.

Theriot Canal / Lake Boeuf / Bayou Boeuf:

1. The headwater flow was set to the estimated flow at TC-1 (average of values for June 17 and June 18).
2. Because the estimated flow at TC-3 (average of values for June 17 and June 18) was similar to the headwater flow, the incremental inflow for Theriot Canal was set to zero.
3. The tributary flow for Bowie Canal was set to the estimated flow at BoC-1 (average of values for June 17 and June 18).
4. The incremental inflow for Lake Boeuf and Bayou Boeuf was set to zero because the estimated and measured flows in BBf-1 and BBf-3 (average of values for June 17 and June 18) were similar to the modeled flows without adding any incremental inflow. This also indicated that no incremental inflow needed to be added to the downstream reaches of Halpin Canal and Grand Bayou.

4.2.12 Incremental Inflow, Data Types 16, 17, and 18

The incremental flow rates were calculated as described in Section 4.2.11. The values used for model inputs for the incremental inflows are shown in Table E.5. For Halpin Canal, the water quality for the incremental inflow was set to the observed data at HC-1 (based on the assumption that all of the flow at HC-1 is from incremental inflow). For Grand Bayou, the water quality values for incremental inflow were set averages of observed water quality data at LPC-1 and BO-1.

4.2.13 Nonpoint Source Loads, Data Type 19

Nonpoint source loads which were not associated with a flow are input into this part of the model. These loads can be most easily understood as resuspended load from the bottom sediments and are modeled as SOD, CBOD_u loads, and NBOD_u loads. These loads were used as calibration parameters and adjusted to get the model to match observed data. The values used for the model input data for nonpoint source loads are shown in Table E.4 in Appendix E.

4.2.14 Headwaters, Data Types 20, 21, and 22

Headwater inputs were specified for Theriot Canal, Halpin Canal, and Grand Bayou. The headwater flow rates were calculated as described in Section 4.2.11. The water quality for the headwaters was based on observed data at stations TC-1, HC-1, and GB-1. The headwater DO values were based on daily average DO values for the sampling day from continuous monitoring data. Calculations for daily minimum and daily average DO from continuous monitoring data are shown in Appendices H1 and H2. The values used for model inputs for the headwaters are shown in Table E.6 in Appendix E.

4.2.15 Wasteloads, Data Types 24, 25, and 26

Four tributaries and two point source discharges were simulated in the model. Other existing point sources were not simulated because they are small and distant from the modeled waterbodies. The four tributaries in the model were Bowie Canal, Bayou Onion, Pitre Lening Canal, and Unnamed Canal (tributary to Halpin Canal). The flow rates for these tributaries were calculated as described in Section 4.2.11. Water quality inputs for the tributaries were based on observed data for stations BoC-1, BO-1, and LPC-1. Inputs for the two point sources (Kraemer Bridge and Boeuf Elementary School) were based on expected flows, BOD5 permit limits, assumed ratios of NBOD to CBOD from the LTP, and an assumed DO value from the LTP. The values used for model inputs for the wasteloads are shown in Table E.7 in Appendix E.

4.2.16 Lower Boundary Conditions (Data Type 27)

Because dispersion was explicitly simulated in the model, inputs were specified for lower boundary conditions. The values for temperature, salinity, conductivity, and DO were based on averages of observed data collected by a continuous monitor at station LDA-1 during the intensive survey. The CBOD_u and NBOD_u values were calculated from the GSBOD spreadsheet provided by LDEQ based on water quality samples taken at LDA-1. The model inputs for the lower boundary conditions are summarized in Table E.8 in Appendix E.

4.3 Model Discussion and Results

4.3.1 Simulation of Chloride and Conductivity

Before calibrating the water quality, the model predictions for chloride and conductivity were examined to evaluate the flow balance. Plots of predicted and observed chloride and conductivity are shown in Appendix I.

In general, the match between predicted and observed values of conductivity and chloride was poor. This was attributed partially to uncertainty in the incremental inflow concentrations of conductivity and chloride. A second, and probably more significant, cause for the poor match between predicted and observed values was the long residence time of certain parts of the system. For example, the water in Lake Boeuf that was sampled during the field survey may have entered the lake a month or two (or more) prior to the survey, at which time the headwater and tributary concentrations of chloride and conductivity may have been much different than during the survey. Because of the uncertainty of incremental inflow concentrations and the lack of steady state conditions, the flow balance was not adjusted to improve the match between predicted and observed values of chloride and conductivity.

4.3.2 Water Quality Calibration Results

Plots of predicted and observed values of CBOD_u, NBOD_u, and DO are shown in Appendix J. A printout of the tabular model output is included in Appendix K. Plots of predicted and observed DO are also shown in Figures 4.2 through 4.4.

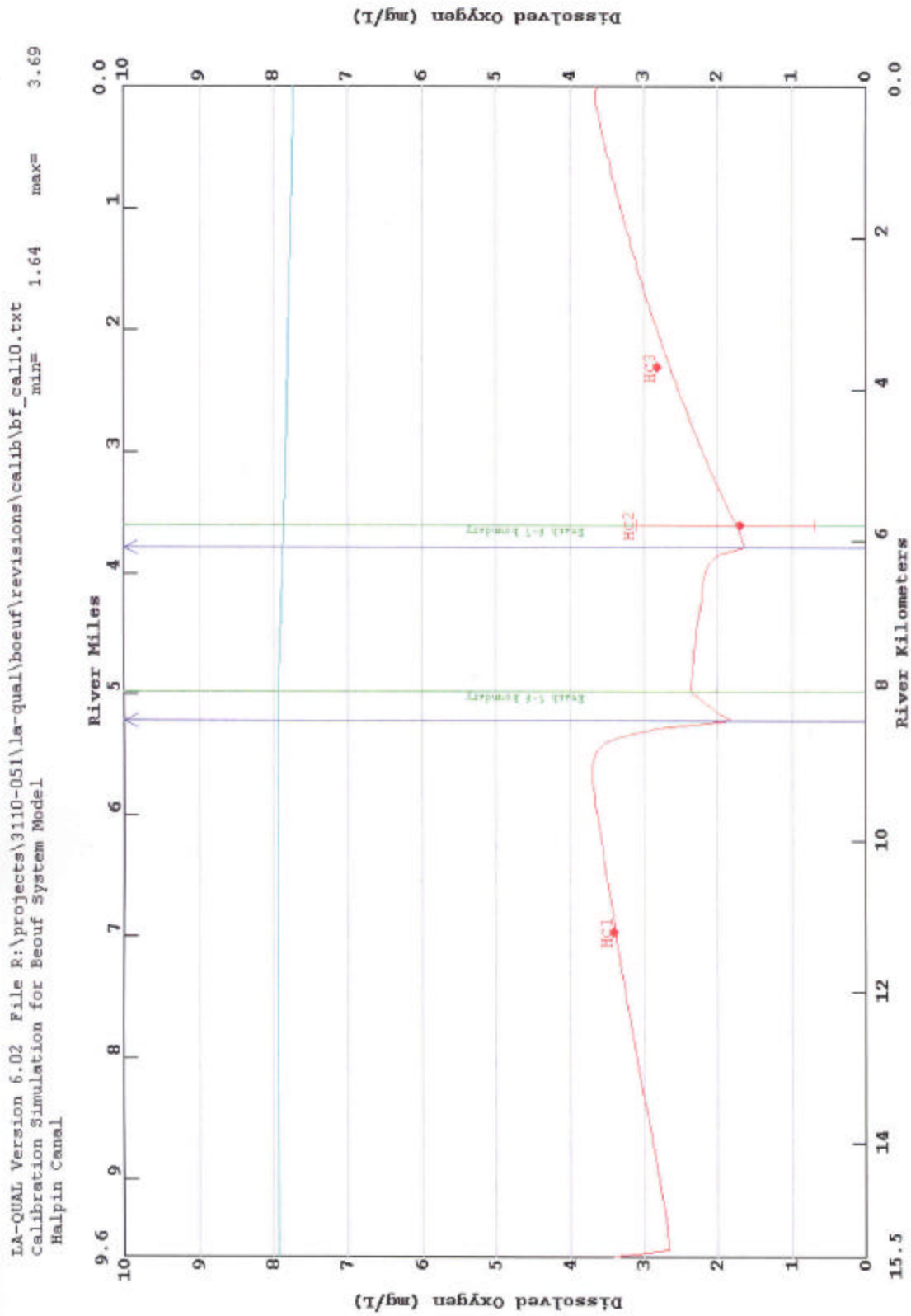


Figure 4.2. Predicted and observed DO for Halpin Canal calibration.

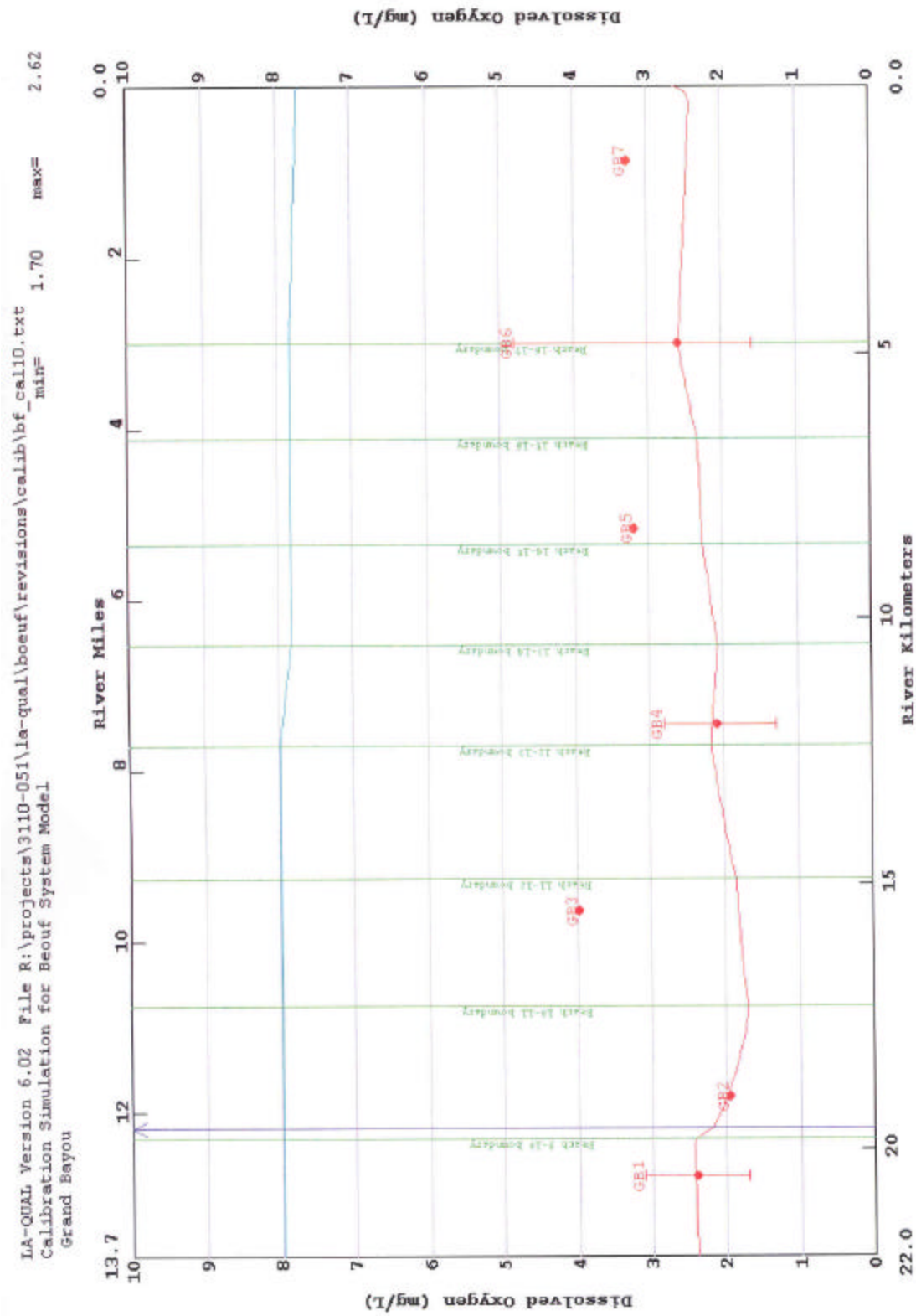


Figure 4.3. Predicted and observed DO for Grand Bayou calibration



In general the calibration results for CBODu and NBODu were good. The model did not consistently underpredict or overpredict the NBODu and CBODu (i.e., no consistent bias).

According to recent LDEQ policy, the DO calibration target at each station was set as shown below based on the diurnal DO fluctuations from the continuous monitoring data:

Diurnal DO fluctuation < 2 mg/L:	daily average DO
Diurnal DO fluctuation 2-9 mg/L:	1 mg/L above daily minimum DO

The diurnal DO fluctuations were determined from continuous monitoring data collected on the day of the water quality sampling (June 18). For each station without continuous monitoring data, the daily average and daily minimum DO were estimated using continuous monitoring data from a nearby station. The ratio of the instantaneous DO to daily average (or daily minimum) DO at each continuous monitoring station was calculated for 15 minute intervals throughout the day. Then each instantaneous DO at a station without continuous monitoring was divided by the ratio corresponding to the time at which the instantaneous value was measured (see calculations in Appendices H1 and H2).

The calibration results for DO were good. The predicted DO values were similar to the calibration targets at all stations except GB-3, GB-5, and GB-7, which had DO calibration target values that were higher than other stations along Grand Bayou.

5. Water Quality Projections

Since the calibrated model indicated that the DO criterion was not being met, no-load scenarios were performed in addition to the traditional summer and winter projections.

5.1 Critical Conditions, Seasonality and Margin of Safety

The Clean Water Act requires the consideration of the seasonal variation of the conditions affecting the constituent of concern, and the inclusion of a margin of safety (MOS) in the development of a TMDL.

Critical conditions for dissolved oxygen were determined by calculating 90th percentile temperatures for each season for subsegments 020102 and 020103 using long term water quality data from the LDEQ Ambient Monitoring Network. The 90th percentile temperatures were calculated using recorded values from station 0083 ("Grand Bayou near Chegby (Chackbay), LA"). These calculations are shown in Appendix L.

Graphical and regression analysis techniques have been used by LDEQ historically to evaluate the temperature and dissolved oxygen data from the Ambient Monitoring Network and run-off determinations from the Louisiana Office of Climatology water budget. Since nonpoint loading is conveyed by run-off, this was a reasonable correlation to use. Temperature is strongly inversely proportional to dissolved oxygen and moderately inversely proportional to run-off. Dissolved oxygen and run-off are also moderately directly proportional. The analysis concluded that the critical conditions for stream dissolved oxygen concentrations were those of negligible nonpoint run-off and low stream flow combined with high stream temperature.

When the rainfall run-off (and non-point loading) and stream flow are high, turbulence is higher due to the higher flow and the temperature is lowered by the run-off. In addition, run-off coefficients are higher in cooler weather due to reduced evaporation and evapotranspiration, so that the high flow periods of the year tend to be the cooler periods. Reaeration rates and DO saturation are, of course, much higher when water temperatures are cooler, but BOD decay rates are much lower. For these reasons, periods of high loading are periods of higher reaeration and dissolved oxygen but not necessarily periods of high BOD decay.

This phenomenon is interpreted in TMDL modeling by assuming that nonpoint loading associated with flows into the stream are responsible for the benthic blanket which accumulates on the stream bottom and that the accumulated benthic blanket of the stream, expressed as SOD and/or resuspended BOD in the calibration model, has reached steady state or normal conditions over the long term and that short term additions to the blanket are off set by short term losses. This accumulated loading has its greatest impact on the stream during periods of higher temperature and lower flow. The manmade portion of the NPS loading is the difference between the calibration load and the reference stream load where the calibration load is higher. The only mechanism for changing this normal benthic blanket condition is to implement best management practices and reduce the amount of nonpoint source loading entering the stream and feeding the benthic blanket.

Critical season conditions were simulated in the dissolved oxygen TMDL projection modeling by using the default flows from the Louisiana Technical Procedures Manual (LTP), and the 90th percentile temperatures. Incremental inflow was assumed to be zero; model loading was from perennial tributaries, sediment oxygen demand, and resuspension of sediments.

In reality, the highest temperatures occur in July-August, the lowest stream flows may occur in other months, and the maximum nonpoint source loading occurs following a significant rainfall, i.e., high-flow conditions. The summer projection model is established as if all these conditions happened at the same time. The winter projection model accounts for the seasonal differences in flows and BMP efficiencies. Other conservative assumptions regarding rates and loadings are also made during the modeling process. In addition to the conservative measures, an explicit MOS of 20% was used for all manmade loads to account for future growth, safety, model uncertainty, and data inadequacies.

5.2 Input Data Documentation

The values and sources of the input data used for the summer projection, summer no load, winter projection, and winter no load scenarios are shown in Appendix M. Except as mentioned below, the projection inputs were unchanged from the calibration.

5.2.1 Initial Conditions, Data Type 11

The initial temperatures were set to the 90th percentile temperature for each season in accordance with the LTP. The initial DO and salinity values were unchanged from the calibration.

5.2.2 SOD and Nonpoint Sources, Data Types 12 and 19

The nonpoint source values were calculated for each projection scenario using a load equivalent spreadsheet. An analysis was made of the calibration nonpoint source and SOD loads in terms of total loading in units of g O₂/m²/day and compared to the reference stream loads in the same terms (which accounted for the width differences between the reference and the modeled streams). All of the calibration loads per unit area were larger than background values. The same spreadsheet also calculated load reductions for the headwaters and tributaries.

LDEQ has collected and measured the CBOD and NBOD oxygen demand loading components for a number of years. These loads have been found in all streams including the non-impacted reference streams. It is LDEQ's opinion that much of this loading is attributable to runoff loads which are flushed into the stream during runoff events, and subsequently settle to the bottom in the slow moving streams. These benthic loads decay and breakdown during the year, becoming easily resuspended into the water column during the low flow/high temperature season. This season has historically been identified as the critical dissolved oxygen season.

LDEQ simulates part of the nonpoint source oxygen demand loading as resuspended benthic load and SOD. The calibrated nonpoint loads (CBOD_u, NBOD_u, and SOD) are summed to produce the total calibrated benthic load. The total calibrated benthic load is then reduced by the

total background benthic load (determined from LDEQ's reference stream research) to determine the total manmade benthic loading. The manmade portion is then reduced incrementally on a percentage basis to determine the necessary percentage reduction of manmade loading required to meet the water body's dissolved oxygen criteria. These reductions are applied uniformly to all reaches sharing similar hydrology and land uses.

Following the same protocol as the point source discharges, the total reduced manmade benthic load is adjusted for the margin of safety by dividing the value by one minus the margin of safety. This adjusted load is added back to the total background benthic value to obtain the total projection model benthic load. This total projection benthic load is then broken out into its components of SOD, resuspended CBOD, and resuspended NBOD by multiplying the total projection benthic load by the ratio of each calibrated component to the total calibrated benthic load.

LDEQ has found variations in the breakdown of the individual CBOD and NBOD components. While the total BOD is reliable, the carbonaceous and nitrogenous component allocation is subject to the type of test method. In the past, LDEQ used a method which suppressed the nitrogenous component to obtain the carbonaceous component value, which was then subtracted from the total measured BOD to determine the nitrogenous value. The suppressant in this method was only reliable for twenty days thus leading to the assumption that the majority of the carbonaceous loading was depleted within that period of time. The test results supported this assumption. Recently the suppressant started failing around day seven and the manufacturer of the suppressant will only guarantee its potency for a five day period. LDEQ felt a five day test would not adequately depict the water quality of streams and began a search for a new test method. The research found a new proposed method for testing long term BODs in Standard Methods.

This proposed method is a sixty day test which measures the incremental total BOD of the sample while at the same time measuring the increase in nitrite/nitrate in the sample. This increase in nitrite/nitrate allows LDEQ to calculate the incremental nitrogenous portion by multiplying the increase by 4.57 to determine the NBOD daily readings. These NBOD daily readings are then subtracted from the daily readings for total BOD to determine the CBOD daily values. A curve fit algorithm is then applied to the daily component readings to obtain the estimated ultimate values of each component as well as the decay rate and lag times of the first order equations.

LDEQ has implemented the new test method over the last several survey seasons. The results obtained using the new method showed that a portion of the CBOD first order equation does begin to level off prior to the twentieth day; however a secondary CBOD component begins to use dissolved oxygen sometime between day ten and day twenty-five. This secondary CBOD component was not being assessed as CBOD using the previous method but was being included in the NBOD load. Thus the CBOD and NBOD component loading used in the reference stream studies is not consistent with the results using the new proposed 60 day method and the individual values should not be used to determine background values for samples processed using the new test method. However, the sum of CBOD and NBOD should be about the same for

both new and old test methods. For this reason, background values in this model are based on the sum of reference stream benthic loads.

LDEQ's reference stream data were examined to identify reference streams that might be applicable for estimating background loads for the Bayou Boeuf system. Although none of the reference streams is located in or near the Barataria basin, four reference streams were identified as having some characteristics (i.e., sediment type, depth, velocity) similar to streams in these subsegments. The nonpoint source loads estimated by LDEQ for these four reference streams are shown in Table 5.1 below. Based on previous experience with DO TMDLs in Louisiana, the total nonpoint source loads for Saline Bayou and Beaucoup Bayou (3.9 to 4.0 g/m²/day) seemed unreasonably high as estimates of background loading for these subsegments. Therefore, the background load for these subsegments was set to 2.0 g/m²/day based on the estimated loads for Big Roaring Bayou and Indian Bayou.

Background concentrations of CBODu and NBODu in the headwaters were also estimated based on LDEQ's reference stream data. Concentrations of CBODu and NBODu in these four reference streams are shown in Table 5.1. The concentrations were lower for Saline Bayou than for the other three streams, which could be due to the fact that Saline Bayou had more flow than the other three streams. Because the Bayou Boeuf system has very little advective flow during critical conditions, the background concentrations for the Bayou Boeuf system were based on values for Big Roaring Bayou, Indian Bayou, and Beaucoup Bayou (all of which were not flowing during the surveys). Based on data for these three streams, a concentration of 9 mg/L of total BODu (i.e., sum of CBODu and NBODu) was selected as the background value. However, the LDEQ TMDL spreadsheet requires individual concentrations of CBODu and NBODu. Therefore, the background concentration of total BODu was divided between CBODu and NBODu based on the ratio of CBODu to NBODu for each inflow in the calibration.

Table 5.1. Data from selected LDEQ reference streams (Smythe 1999).

	Big Roaring Bayou	Indian Bayou	Beaucoup Bayou	Saline Bayou Site 2-3
Sediment type	silt	silt	silt	silt
Velocity during survey (m/sec)	0.00	0.00	0.00	0.23
Depth during survey (m)	1.08	0.64	0.67	0.93
NPS CBODu load (g/m ² /day)	0.688	0.218	0.169	0.531
NPS NBODu load (g/m ² /day)	0.095	0.090	0.498	1.637
SOD at 20°C (g/m ² /day)	1.45	1.52	4.20	2.25
Temperature during survey (°C)	20.15	20.82	16.45	16.11
SOD at stream temp. (g/m ² /day)	1.46	1.60	3.36	1.76
Total NPS load (g/m ² /day)	2.24	1.91	4.03	3.93
CBODu concentration (mg/L)	3.48	2.94	2.72	1.60
NBODu concentration (mg/L)	5.41	7.26	5.80	3.70

5.2.3 Incremental Inflow, Data Types 16, 17, and 18

The incremental inflows were set to zero to simulate critical low flow conditions (as discussed in section 5.1).

5.2.4 Headwaters, Data Types 20, 21, and 22

Since there were no USGS flow gages and no published 7Q10 values for these subsegments, the flow rate for each headwater was set to 0.1 cfs ($0.003 \text{ m}^3/\text{sec}$) for summer and 1.0 cfs ($0.03 \text{ m}^3/\text{sec}$) for winter as specified in the LTP. Headwater concentrations of CBODu and NBODu were set based on background concentrations and percent reduction calculations in the spreadsheets discussed in Section 5.2.2.

For the projections for the Bayou Boeuf system, it was assumed that reductions of CBODu and NBODu in headwater and tributary inflows would also result in improvements in the DO concentrations of those inflows. Therefore, the DO concentrations for headwater and tributary inflows were set assuming that percent saturation values from the calibration represented no reduction of nonpoint sources, 90% saturation represented complete reduction of manmade nonpoint sources, and 100% saturation represented complete reduction of manmade and natural nonpoint sources. Calculations for the inflow DO values used in the model are presented in Table M.21 (Appendix M).

5.2.5 Wasteloads, Data Types 24, 25, and 26

Since there were no USGS flow gages and no published 7Q10 values for these subsegments, the flow rate for each tributary in the model was set to 0.1 cfs ($0.003 \text{ m}^3/\text{sec}$) for summer and 1.0 cfs ($0.03 \text{ m}^3/\text{sec}$) for winter as specified in the LTP. Headwater concentrations of CBODu and NBODu were set based on background concentrations and percent reduction calculations in the spreadsheets discussed in Section 5.2.2. The tributary DO concentrations were set in the same manner as for the headwaters (as described in Section 5.2.4).

For the two point source discharges, the model inputs for the projections were the same as for the calibration.

5.2.6 Lower Boundary Conditions (Data Type 27)

The temperatures for the lower boundary conditions were set equal to the 90th percentile temperature for each season. The DO values were set following the same methodology as for other boundaries in the model (i.e., headwater and tributaries; see Section 5.2.4). This methodology was used for the lower boundary because it was assumed that nonpoint source load reductions in the Bayou Chevreuil and Bayou Boeuf watersheds would improve the water quality in the southwest corner of Lac des Allemands. The CBODu and NBODu concentrations were reduced from the calibration values using the LDEQ TMDL spreadsheet in the same way as for the headwaters and tributaries. The other lower boundary inputs were unchanged from the calibration.

5.3 Model Discussion and Results

5.3.1 No Load Scenarios

The summer and winter no load scenarios were run to predict DO concentrations with no manmade sources under critical conditions. Printouts of the spreadsheets with nonpoint source load calculations for these scenarios are presented in Appendix N. Graphs of the predicted DO and printouts of the tabular output are presented in Appendix O.

The minimum predicted DO values from the no load scenarios were 3.5 mg/L for summer and 5.6 mg/L for winter. In other words, these simulations showed that complete elimination of man-made sources would result in DO values well below the current standard during summer and slightly above the standard during winter. Based on these results, the current DO standard for these subsegments should definitely be reevaluated for summer.

5.3.2 Summer and Winter Projections

The summer and winter projection simulations were run to determine the allowable loadings and percent reductions for the Bayou Boeuf system that would result in the existing DO standard being maintained. Printouts of the spreadsheets with nonpoint source load calculations for these scenarios are presented in Appendix P. Graphs of the predicted DO and printouts of the tabular output for these scenarios are presented in Appendix Q. Graphs of the predicted DO are also shown in Figures 5.1 through 5.6.

As shown in Table 5.2, the load reductions that were required for the model to show the DO standard being met in both subsegments included both a complete elimination of man-made nonpoint sources plus some reduction of background nonpoint sources in the summer. For each scenario, a uniform percent reduction was applied to all reaches in the model because the hydrology and land uses appeared to be similar for all reaches.

Table 5.2. Summary of nonpoint source load reductions required to meet the DO standard.

	Man-made nonpoint sources	Background nonpoint sources
Summer (May – October)	100%	37%
Winter (November – April)	92%	0%

5.4 Calculated TMDL, WLAs, and LAs

5.4.1 Outline of TMDL Calculations

An outline of the TMDL calculations is provided below to assist in understanding the TMDL calculations, which are shown in Appendix P. Slight variances may occur based on individual cases. All of the TMDL calculations were done using the LDEQ TMDL spreadsheet.

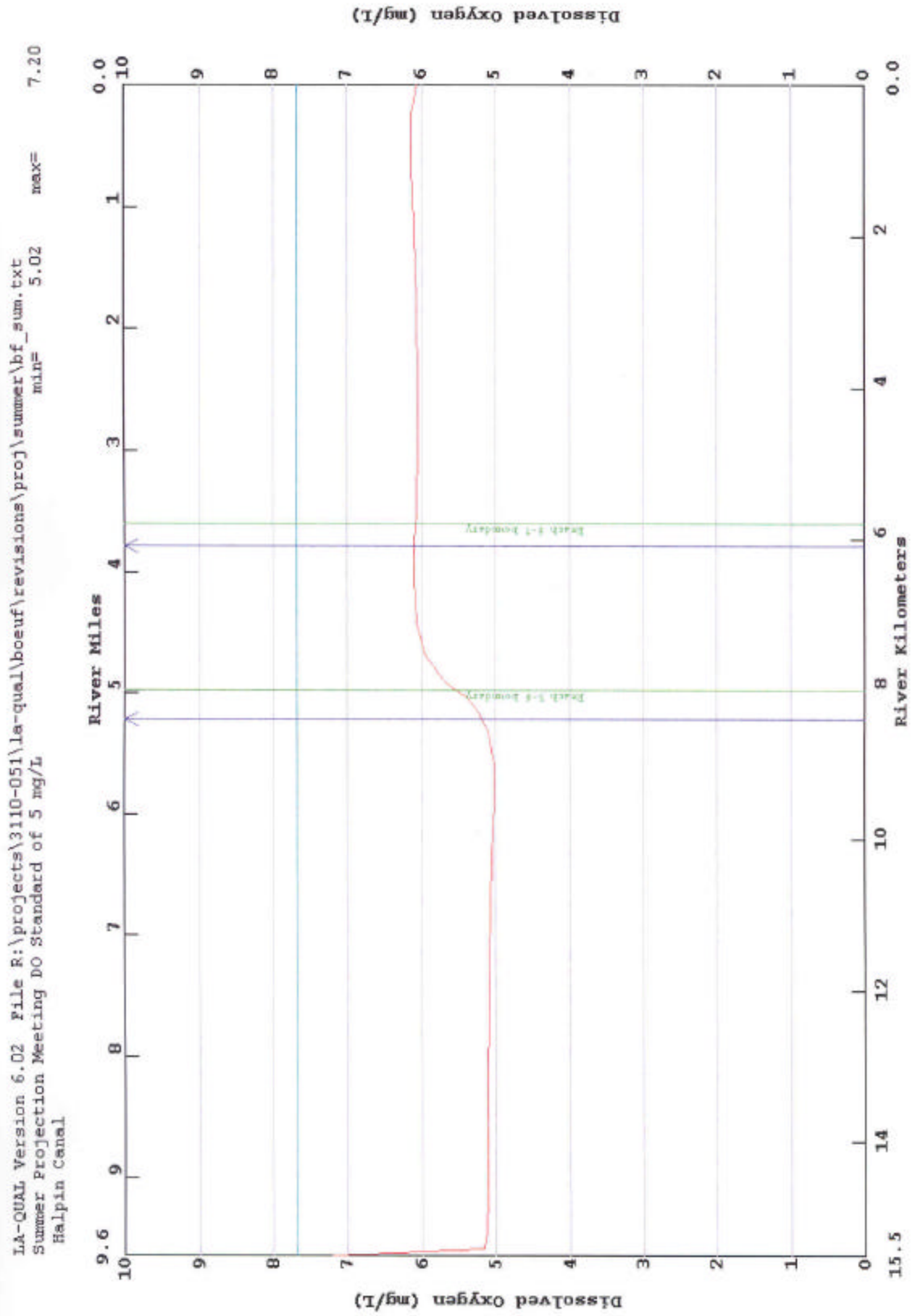


Figure 5.1. Predicted DO for Halpin Canal summer projection

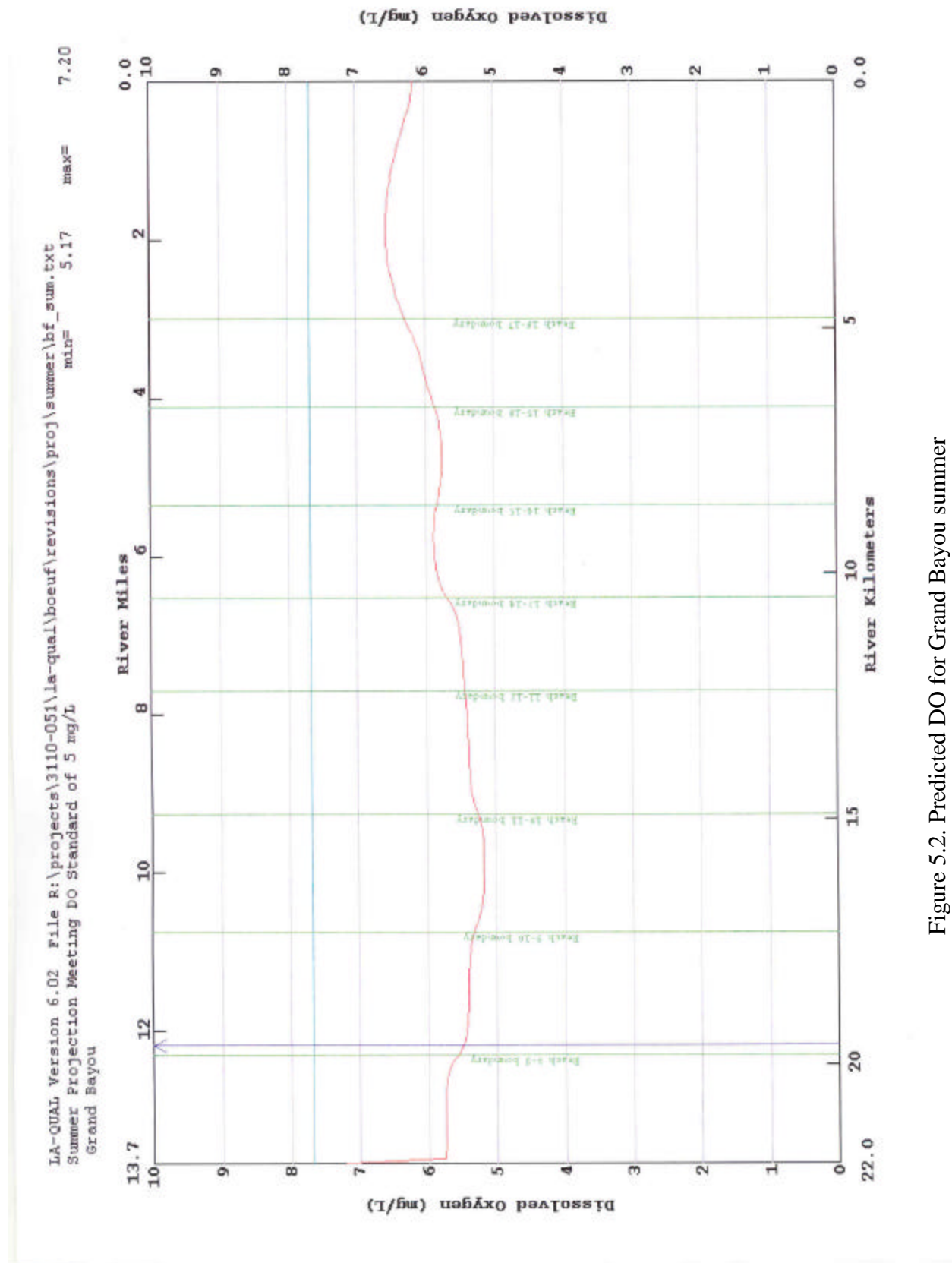


Figure 5.2. Predicted DO for Grand Bayou summer

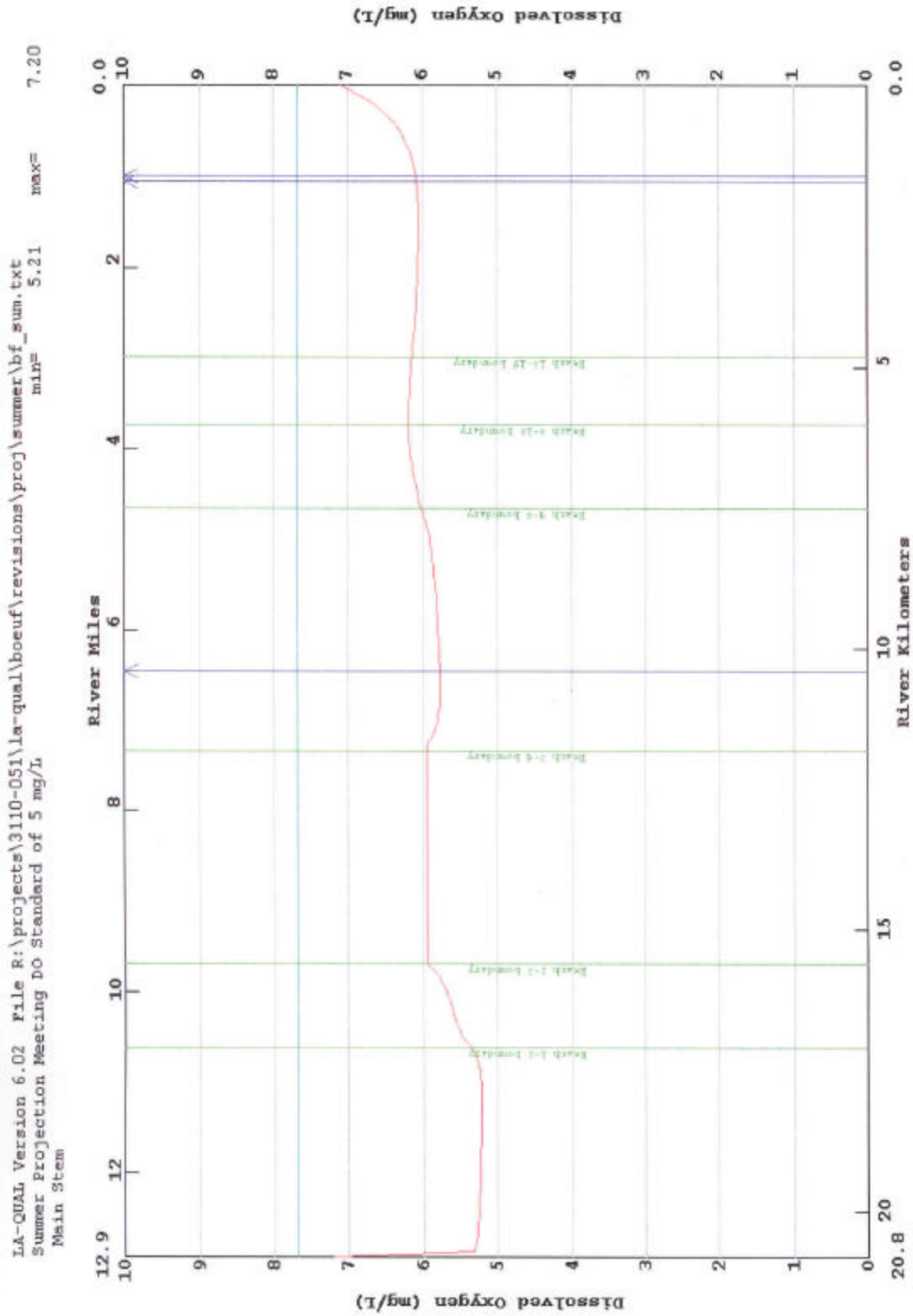


Figure 5.3. Predicted DO for the main stem summer projection

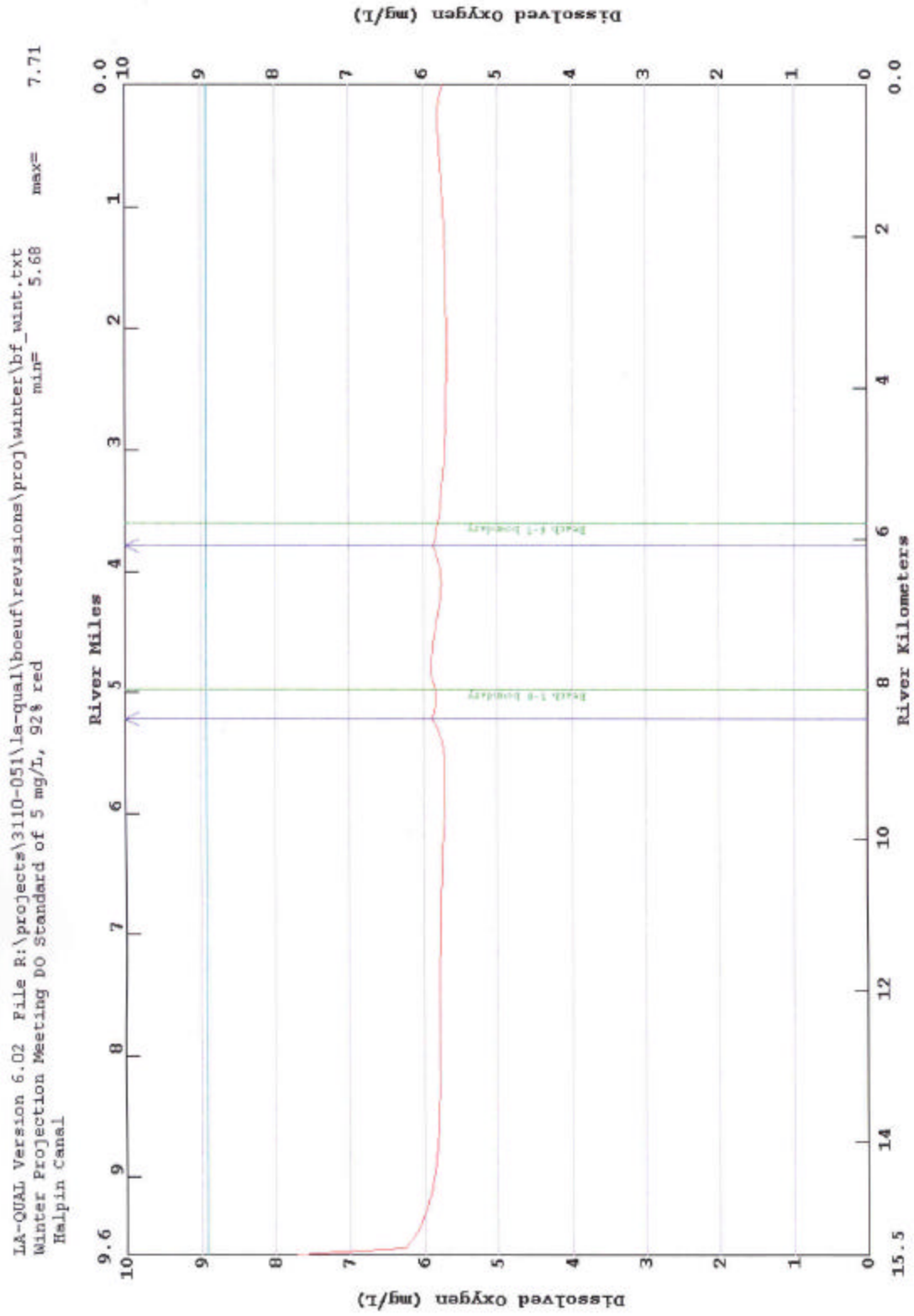


Figure 5.4. Predicted DO for Halpin Canal winter

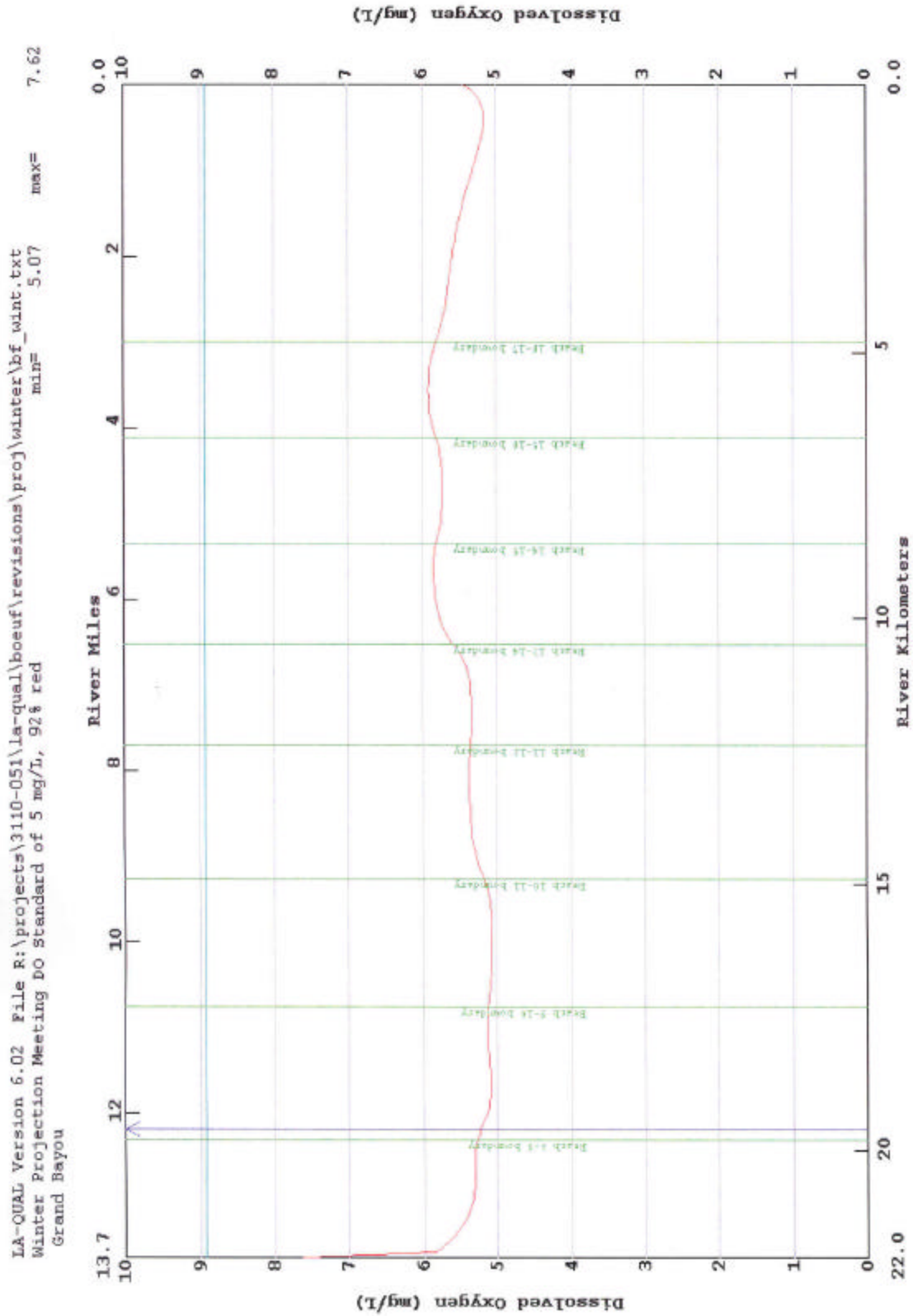


Figure 5.5. Predicted DO for Grand Bayou winter projection

Figure 5.6. Predicted DO for the main stem winter projection

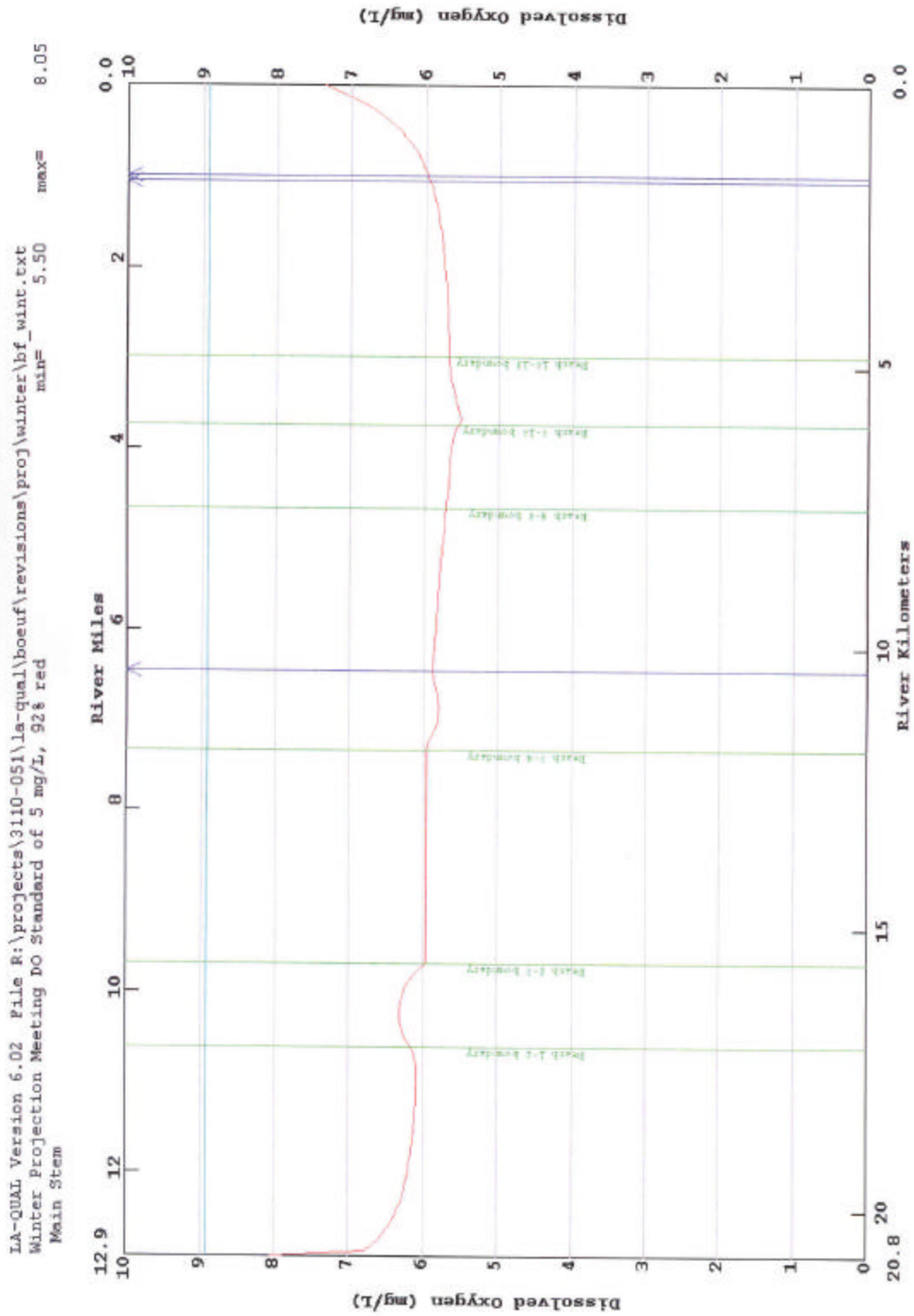


Figure 5.6. Predicted DO for the main stem winter projection

A) The natural background benthic loading was estimated from reference stream resuspension (nonpoint CBOD and NBODu) and SOD load data.

B) The calibration man-made benthic loading was determined as follows:

- Calibration resuspension and SOD loads were summed for each reach as $\text{g/m}^2/\text{day}$ of oxygen demand to get the calibration benthic loading.
- The natural background benthic loading was subtracted from the calibration benthic loading to obtain the man-made calibration benthic loading.

C) Projection benthic loads are determined by trial and error during the modeling process using a uniform percent reduction for resuspension and SOD. The design flows of the point sources were increased to obtain an explicit MOS of 20%. Headwater and tributary concentrations of CBODu, NBODu, and DO range from reference stream levels to calibration levels based on the characteristics of the headwater. Where headwaters and tributaries exhibit man-made pollutant loads in excess of reference stream values, the loadings are reduced by the same uniform percent reduction as the benthic loads.

- The projection benthic loading at 20°C is calculated as the sum of the projection resuspension and SOD components expressed as $\text{g/m}^2/\text{day}$ of oxygen demand.
- The natural background benthic load is subtracted from the projection benthic load to obtain the man-made projection benthic load for each reach.
- The percent reduction of man-made loads for each reach is determined from the difference between the projected man-made nonpoint load and the man-made nonpoint load found during calibration.
- The projection loads are also computed in units of lbs/day and kg/day for each reach.

D) The total stream loading capacity at critical water temperature is calculated as the sum of:

- Headwater and tributary CBODu and NBODu loading in lbs/day and kg/day.
- The natural and man-made projection benthic loading for all reaches of the stream is converted to the loading at critical temperature and summed in lbs/day and kg/day.
- Point source CBODu and NBODu loading in lbs/day and kg/day.
- The margin of safety in lb/day and kg/day.

5.4.2 Results of TMDL Calculations

The TMDLs for the biochemical oxygen demanding constituents (CBOD_u, NBOD_u, and SOD) were calculated for the summer and winter critical seasons. Printouts of the TMDL spreadsheets are presented in Appendix P. A summary of the loads is presented in Tables 5.3 and 5.4.

The nonconservative behavior of dissolved oxygen allows many small and remote point source dischargers to be assimilated by their receiving waterbodies before they reach the modeled waterbody. These dischargers are said to have very little to no impact on the modeled waterbody and therefore, they are not included in the model and are not subject to any reductions based on this TMDL. These facilities are permitted in accordance with state regulation and policies that provide adequate protective controls. New similarly insignificant point sources will continue to be issued permits in this manner. Significant existing point source dischargers are either included in the model or are determined to be insignificant by other modeling. New significant point source dischargers would have to be evaluated individually to determine what impact they have on the impaired waterbody and the appropriate controls.

The point source wasteload allocation (WLA) includes loads from all permitted point sources within the subsegment that are known to discharge oxygen demanding effluent. For these subsegments, seven point sources were not included in the model because they are small and far away from the modeled waterbodies. Their loads were accounted for in the model by calibration as part of the boundary conditions or nonpoint source loading.

The LDEQ TMDL spreadsheet applies a user-specified explicit MOS to the point source loads and to the man-made nonpoint source loads (i.e., all man-made sources). The explicit MOS that was specified in the spreadsheet was 20%. For summer, this TMDL required a complete elimination of the man-made nonpoint source loads, thereby eliminating the need for a MOS for that portion of the load for summer.

It should be noted that the 20% explicit MOS accounts for future growth as well as uncertainties associated with the modeling process. The TMDL also includes an implicit MOS created by conservative assumptions in the modeling (see Section 5.1).

Table 5.3. TMDL for subsegment 020102 (sum of CBOD_u, NBOD_u, and SOD).

	Load (kg/day) for:	
	Summer (May-Oct)	Winter (Nov-Apr)
Point Source WLA	123	123
Point Source Reserve MOS	31	31
Natural Nonpoint Source LA	2732	3772
Man-made Nonpoint Source LA	0	420
Man-made Nonpoint Source MOS	0	105
TMDL	2886	4451

Table 5.4. TMDL for subsegment 020103 (sum of CBODu, NBODu, and SOD).

	Load (kg/day) for:	
	Summer (May-Oct)	Winter (Nov-Apr)
Point Source WLA	0	0
Point Source Reserve MOS	0	0
Natural Nonpoint Source LA	9003	13360
Man-made Nonpoint Source LA	0	7
Man-made Nonpoint Source MOS	0	2
TMDL	9003	13369

6. Sensitivity Analysis

All modeling studies necessarily involve uncertainty and some degree of approximation. It is therefore of value to consider the sensitivity of the model output to changes in model coefficients, and in the hypothesized relationships among the parameters of the model. The LA-QUAL model allows multiple parameters to be varied with a single run. The model adjusts each parameter up or down by the percentage given in the input set. The rest of the parameters listed in the sensitivity section are held at their original value. Thus the sensitivity of each parameter is reviewed separately. A sensitivity analysis was performed on the calibration scenario. Parameters were varied by +/- 30%, except temperature, which was adjusted +/- 2 degrees Centigrade. The results of the sensitivity analysis are summarized in Table 6.1.

The model was most sensitive to stream reaeration, stream depth, SOD, temperature, and stream velocity. Most of the minimum DO values occurred in Halpin Canal near the two tributaries (Pitre Lening and Unnamed Canal). None of them occurred in the main stem (Theriot Canal / Lake Boeuf / Bayou Boeuf).

Table 6.1. Summary of calibration model sensitivity analysis.

Parameter	Negative Parameter Changes			Positive Parameter Changes		
	Parameter Change	Minimum DO (mg/L)	Percentage Difference in DO	Parameter Change	Minimum DO (mg/L)	Percentage Difference in DO
Stream Reaeration	-30%	1.28	-21.0%	30%	2.09	29.0%
Stream Depth	-30%	1.99	22.8%	30%	1.31	-19.1%
Benthic Demand (SOD)	-30%	2.02	24.7%	30%	1.39	-14.2%
Initial Temperature	-2°C	1.84	13.6%	2°C	1.47	-9.3%
Stream Velocity	-30%	1.44	-11.1%	30%	1.78	9.9%
Wasteload DO	-30%	1.51	-6.8%	30%	1.77	9.3%
Incremental Flow Rate	-30%	1.50	-7.4%	30%	1.71	5.6%
Headwater Flow	-30%	1.49	-8.0%	30%	1.64	1.2%
CBOD Decay Rate	-30%	1.70	4.9%	30%	1.59	-1.9%
Wasteload Flow	-30%	1.57	-3.1%	30%	1.67	3.1%
Incremental DO	-30%	1.60	-1.2%	30%	1.69	4.3%
NBOD Decay Rate	-30%	1.66	2.5%	30%	1.61	-0.6%
Wasteload CBOD	-30%	1.67	3.1%	30%	1.62	0.0%
Incremental CBOD	-30%	1.66	2.5%	30%	1.63	0.6%
Incremental NBOD	-30%	1.65	1.9%	30%	1.64	1.2%
Headwater CBOD	-30%	1.64	1.2%	30%	1.64	1.2%
Headwater NBOD	-30%	1.64	1.2%	30%	1.64	1.2%
Lower Boundary DO	-30%	1.64	1.2%	30%	1.64	1.2%
Lower Boundary CBOD	-30%	1.64	1.2%	30%	1.64	1.2%
Lower Boundary NBOD	-30%	1.64	1.2%	30%	1.64	1.2%
Wasteload NBOD	-30%	1.65	1.9%	30%	1.63	0.6%
Headwater DO	-30%	1.61	-0.6%	30%	1.64	1.2%

7. Conclusions

The summer projection required man-made loads to be completely eliminated and background loads to be reduced by 37% while the winter projection required man-made loads to be reduced by 92% to maintain a minimum DO of 5.0 mg/L during critical conditions.

These subsegments were listed as impaired due to nutrients as well as organic enrichment / low DO. These TMDLs establish load limitations for oxygen-demanding substances and goals for reduction of those pollutants. LDEQ's position, as stated in the declaratory ruling issued by Dale Givens regarding water quality criteria for nutrients (*Sierra Club v. Givens*, 710 So.2d 249 (La. App. 1st Cir. 1997), writ denied, 705 So.2d 1106 (La. 1998)), is that when oxygen-demanding substances are controlled and limited in order to ensure that the dissolved oxygen criterion is supported, nutrients are also controlled and limited. The implementation of this TMDL through wastewater discharge permits and implementation of best management practices to control and reduce runoff of soil and oxygen-demanding pollutants from nonpoint sources in the watershed will also control and reduce the nutrient loading from those sources.

These TMDLs have been developed to be consistent with the State antidegradation policy (LAC 33:IX.1109.A).

LDEQ will work with other agencies such as local Soil Conservation Districts to implement agricultural best management practices in the watershed through the 319 programs. LDEQ will also continue to monitor the waters to determine whether standards are being attained.

In accordance with Section 106 of the Federal Clean Water Act and under the authority of the Louisiana Environmental Quality Act, the LDEQ has established a comprehensive program for monitoring the quality of the state's surface waters. The LDEQ Surveillance Section collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state's surface waters, to develop a long-term data base for water quality trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state's biennial 305(b) report (*Water Quality Inventory*) and the 303(d) list of impaired waters. This information is also utilized in establishing priorities for the LDEQ nonpoint source program.

The LDEQ has implemented a watershed approach to surface water quality monitoring. Through this approach, the entire state is sampled over a four-year cycle. Long-term trend monitoring sites at various locations on the larger rivers and Lake Pontchartrain are sampled throughout the four-year cycle. Sampling is conducted on a monthly basis to yield approximately 12 samples per site each year the site is monitored. Sampling sites are located where they are considered to be representative of the waterbody. Under the current monitoring schedule, approximately one-half of the state's waters are newly assessed for 305(b) and 303(d) listing purposes for each biennial cycle with sampling occurring statewide each year. The four year cycle follows an initial five year rotation which covered all the basins in the state according to the TMDL priorities. This will allow the LDEQ to determine whether there has been any improvement in

water quality following implementation of the TMDLs. As the monitoring results are evaluated at the end of each year, waterbodies may be added to or removed from the 303(d) list.

8. References

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